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REVIEWING THE INTERLINKED FRAMEWORKS OF DOCTORAL TRAINING CENTERS: ACHIEVEMENTS AND OBSTACLES TO MAINTAINING SUSTAINABILITY

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Abstract: Transdisciplinarity is a critical element in the DTP/C model, and this paper highlights the importance of transparent communication, clear goal-setting, and non-coercive consent with students. The paper also stresses the need to strengthen formal and institutional structures that address the needs and requirements of all actors involved in the DTP/C. The review identifies the contributions and sustainability challenges of the transdisciplinary models in DTP/C. Contributions include the creation of a space where interdisciplinary teams can work together to solve complex problems, the development of new research methods, the creation of new research questions, and the production of more significant research outputs. Sustainability challenges include the need for long-term funding and support, the need for flexible organizational structures, and the challenges of maintaining relationships with external partners. Overall, this review highlights the significance of transdisciplinary models in DTP/C and their contribution to producing knowledge to address complex problems. It also emphasizes the importance of creating sustainable structures that can support these models in the long term.

Keywords: doctoral training programs, doctoral training centers, transdisciplinarity, co-production, sustainability challenges.

INTRODUCTION

"**I**t takes an academy to raise a scholar" (Chiappetta-Swanson & Watt, 2011). It is never an individual task but rather a collective and institutional involvement with multiple partners and stakeholders to raise and nurture a scholar for the complex world. As the world becomes a knowledge economy, complex and more advanced in technology, so is the increase in the number of doctoral degree holders and doctoral students globally (Nerad, 2011;
Skopek et al., 2020). Real-life complex problems need to be solved through advanced knowledge as a product of various disciplines. Hence, the advent and flooding of master's degrees and doctoral degrees do not come as a surprise. According to Yudkevich et al. (2020), doctoral education remains a critical act of the world. Many developing countries have huge gaps and deficits in trained doctoral graduates managing essential sectors of their economies, the academic environments, and in excess, considering most developed economies.

Over the last decade, the upheld tradition of doctoral scholarships, also known as "lone scholar," has gradually transformed into blocks run by universities and institutions in the United Kingdom, parts of Europe and Africa as Doctoral Training Centers (DTCs), Doctoral Support Programs (DSPs), Centers for Doctoral Training (CDTs) and Doctoral Training Partnerships (DTPs), Graduate Schools, International Doctoral Innovation Center (IDIC), Africa Centers of Excellence (ACE) for postgraduate studies, etc. These centers started as interdisciplinary units that drew experts from various departments with a strategic aim of increasing research activities to solve complex science problems by several United Kingdom universities, the Economic and Social Research Council (ESRC), the Engineering and Physical Sciences Research Council (EPSRC), and the

Arts and Humanities Research Council (AHRC). Within a decade, and by the close of 2014, the model evolved with over 21 accredited DTCs and over 46 institutions in the United Kingdom, with notable universities taking part (EPSRC, 2015). In 2009, the EPSRC awarded £250 m to 44 DTCs to reach over 2000 PhD students within 5 years of sponsorship covering all the DTCs (Bawden, 2009). These excellence centers serve as an opportunity for students to undertake integrated research, training, and learning, focusing on the centers' priority research areas and charting their specialization. Doctoral training programs and centers (DTP/Cs) are important indicators of successful and credible research (Quality Assurance Agency for Higher Education, 2013). As Reis (1997) put it, doctoral programs are apprenticeship programs processes for lecturing, teaching, carrying out laboratory work, organizing and attending seminars, and examining undergraduate research works. They serve as a research and teaching mentoring stage as students prepare to take careers in academia or industry postgraduation.

In the context of this paper, it is argued that the DTP/Cs tend to use transdisciplinary models because of the manifold involvement of different actors surrounding research works at the centers. The multiple involvement acts of DTP/Cs take the form of disciplinary crossing, knowledge coproduction and integration, cooperation, and collaboration of academics and nonacademics. Doctoral candidates use various methodologies and theories in thesis writeups, research is often adopted from different fields and disciplines, and supervisors' inputs often tend to consolidate this praxis. Most industry and government funding support for DTCs/DTPs comes on the drop of using transdisciplinary approaches as a higher-order approach in addressing complex challenges (Crona & Parker, 2012).

However, with all these low-hanging fruits from DTPs/Cs and the effort of academia and industry, executed through doctoral training centers and graduate schools, the real-life experiences of doctoral candidates across

higher education institutions (HEIs) remain underexplored. Doctoral candidates have experienced some significant challenges related to supervision, publications, communication, theoretical positions and disagreements, funding cutbacks, conflict of interest issues, intellectual property rights, collaboration for research and other logistics constraints (Baptista, 2011; Gardner, 2013; Hawkins, 2017; Hill & Thabet, 2021; Lubbe et al., 2005; Mason, 2018; Pyhältö et al., 2012). This paper's concept and signpost focused on how doctoral training centers or programs have become new academic research approaches to addressing the world's growing challenges using transdisciplinary looms and effective communication skills to coproduce knowledge. I identified the DTP/Cs' significant contributions to knowledge coproduction and the gaps inherent in our proposed perspectives on its sustainability.

LITERATURE REVIEW

From 1998 to 2008, the number of doctorates earned annually increased by nearly 40% according to the Organization for Economic CoOperation and Development (OECD). The increasing number of doctorate holders is also fretting that many doctorate holders enter job markets with little guidance on finding employment. While PhD scientists can be valuable and serve essential roles outside academia, several industrial employers have highlighted that doctoral graduates tend to lack the skills they demand. These include practical skills such as teamwork, managing shifting goals, and project management (Cyranoski et al., 2011). Higher education cannot guarantee lucrative employment to its graduates; however, the quality of education and skill development offered play a key role in preparing its graduates for the challenges. Regardless of the specific discipline it offers, a higher education program should arm its students with a much-needed set of practical skills, knowledge, and abilities. Doctoral degrees are a grounding process for launching an academic career in universities and other research institutions (Thune, 2009).

A doctoral degree is a globally recognized indicator of specialization. Research jobs scout employees based on complementary research skills, while non research jobs emphasize practical skills and knowledge. This is where traditional doctoral programs are lacking. They are overly specialized and focus on skills and knowledge highly relevant to academia but not beyond. In some cases, knowledge may not even be transferable between different disciplines or subdisciplines. Communication is difficult between different disciplines and, in some cases, even among the same disciplines, which might be attributed to a lack of cooperation and partnership within the same domains. Researchers within the same discipline are often geared to look at members of the same discipline as competitors (Taylor, 2011). PhD students follow suit in this attitude toward competition/collaboration, with universities needing to emphasize increasing cooperation between and within disciplines. While the doctoral program equips its students with intellectual freedom throughout the journey, there is little or no training on skills that doctoral degree holders need, such as management, budgeting, negotiating, communication, and entrepreneurship. For the ESRC Doctoral Training Partnership at the University of Cambridge and many other DTP/Cs, doctoral students are required to participate in the partnership process of training with the private, public, and civil society sectors, including nonacademic organizations for industrial and corporate experiences (ESRC, 2021). A healthy PhD model requires collaborations between students, academics, industry, community, and government, focusing on scientific and system thinking rather than pure science, according to the EPSRC (2015).

RESEARCH APPROACH

This paper is primarily based on systematic empirical reviews of critical literature related to the study's objective. In particular, the words and phrases used included doctoral training, transdisciplinary knowledge, knowledge coproduction, research, collaboration, challenges and communication, supervision, etc. T The following online databases and sources were searched: Google Scholar, University of Nottingham Library, University for Development Studies Library, The Appalachian State University Library, JSTOR, Research Gate, ELSEVIER, Nature, SCOPUS, SAGE publications, and many other credible and indexed journal sites for relevant literature. These searches revealed hundreds of scholarly publications on the paper's focus area, and 108 relevant articles were read in detail for this study, which excluded several unrelated keywords to the objective, such as doctoral scholarship application processes, requirements, and entering doctoral centers/schools. These texts were omitted because the focus and theme of this paper aimed to highlight the knowledge coproduction process of doctoral research projects in transdisciplinary environments such as the DTP/Cs.

Some of the key phrases used in search engines for the review included but were not limited to doctoral research, PhD research and supervision, doctoral students, doctoral training centers and partnerships, transdisciplinary research, communication, challenges of doctoral studies, knowledge coproduction and management, higher education, graduate school, transdisciplinary models, funding and grants, etc. These texts allowed for review themes that fit and helped amplify the paper's research goal.

RESULTS

Existing Approaches of Doctoral Training Programs

The various DTP/Cs currently in existence tend to be unique in the structure they hold and support doctoral training. These DTP/Cs function by offering a collection of research programs in diverse disciplines for training postgraduate students and equipping them with much-needed skills, knowledge, and experience to tackle global challenges (ESRC, 2015). A major portion of these centers includes partnerships and collaborations within the same institutions and other academic institutes, industries, government bodies, charities, etc. (Steering Group Human Resources and Mobility, 2005). By doing so, they address some of the issues that have been raised by the ever-increasing number of PhD holders in today's work environment.

DTP/Cs, as captured in Table 1, show the cross-disciplinary structure of the centers and their intended areas of focus, which are intertransdisciplinary in nature. They also follow a unique structure for training their students; thus, each program would differ in what it offers its students. Commonly, the emphasis would be on interdisciplinary research collaborations. This would span three to four years to see the students involved in a multidisciplinary research project with a team of established researchers and fellow students. It focuses on taught and training programs offering dedicated credits on specially designed transferrable skills. An additional element incorporated by DTP/Cs is a period of internship or placement within an industrial institution. Moreover, DTP/Cs usually adopt cohort-based training models within a specific start date, with a set number of students recruited into the programs through a regulated recruitment process. Some programs include additional elements, such as Horizon's focus on students developing their research proposal amidst a multisupervisory team during the first 12 months of the program (OECD, 2016).

Table 1

Cross-disciplinary structure of the centers

No	Name
1	Doctoral Training Centre in Sustainable Chemical Technologies
2	Industrial Doctorate Centre in Digital Entertainment
3	Doctoral Training Centre in Hydrogen, Fuel Cells and their Applications
4	Industrial Doctorate Centre in Formulation Engineering
5	Doctoral Training Centre in Structural Metallic Systems for Gas Turbine Applications
6	Doctoral Training Centre in Physical Sciences of Imaging for the Biomedical Sciences
7	Doctoral Training Centre in Complexity Sciences
8	Doctoral Training Centre in Chemical Synthesis
9	Advanced Composites Centre for Innovation and Science, Doctoral Training Centre
10	Industrial Doctorate Centre in Systems
11	Doctoral Training Centre in Functional Nanomaterials
12	Doctoral Training Centre in Future Communications: People, Power and Performance
13	Industrial Doctorate Centre in Composites Manufacture (lead university)
14	Doctoral Training Centre in Analysis
15	Doctoral Training Centre in Assembly of Nano Materials and Nano Devices

16	Doctoral Training Centre in Skills Technology, Research, and Management An Industrial Doctorate Centre for the UK Water Sector
17	Multidisciplinary Centre for Doctoral Training in Energy
18	Industrial Doctoral Centre for Offshore Renewable Energy
19	Doctoral Training Centre in Neuroinformatics and Computational Neuroscience
20	Doctoral Training Centre in Cell and Proteomic Technologies
21	Industrial Doctorate Centre in Optics and Photonics Technologies
22	Doctoral Training Centre in Controlled Quantum Dynamics
23	Doctoral Training Centre in Theory and Simulation of Materials
24	Doctoral Training Centre in Science and Application of Plastic Electronic materials
25	Industrial Doctorate Centre in Non-Destructive Evaluation
26	Doctoral Training Centre in Chemical Biology
27	Energy Futures Doctoral Training Centre
28	Doctoral Training Centre in Statistics and Operational Research
29	High Wire Doctoral Training Centre
30	Doctoral Training Centre in Technologies for a Low Carbon Future
31	Doctoral Training Centre in Tissue Engineering and Regenerative Medicine
32	Doctoral Training Centre in Basic Technologies for molecular-scale Engineering
33	Industrial Doctorate Centre for Innovative and Collaborative Construction Engineering

34	Doctoral Training Centre for Regenerative Medicine
35	Nuclear Fission Research, Science and Technology Doctoral Training Centre
36	Industrial Doctorate Centre in Nuclear Engineering
37	The North West Nanoscience Doctoral Training Centre
38	Doctoral Training Centre for Integrative Systems Biology
39	Doctoral Training Centre in Computer Science
40	Industrial Doctorate in Biopharmaceutical Process Development
41	Industrial Doctorate Centre in Efficient Fossil Energy Technologies
42	Horizon Doctoral Training Centre for the Digital Society
43	From Targeted Therapeutics to Next Generation Medicine: Doctoral Training Centre
44	Industrial Doctorate Centre in Manufacturing Technology
45	Crops for Future Doctoral Training Centre
46	Doctoral Training Centre in Systems Approaches to Biomedical Science
47	Doctoral Training Centre in Systems Biology
48	Doctoral Training Centre in Healthcare Innovation
49	Doctoral Training Centre in Bionanotechnology, Medical Imaging and Bioinformatics
50	Doctoral Training Centre in Digital Music and Media for the Creative Economy
51	Doctoral Training Centre in Technologies for Sustainable Built Environments
52	Doctoral Training Centre in Advanced Metallic Systems—Challenges in Global Competitiveness

53	Doctoral Training Centre in Interdisciplinary Energy Research (E-Futures)
54	Industrial Doctorate Centre in Machining Science
55	Industrial Doctorate Centre in Transport and the Environment
56	Doctoral Training Centre in Complex Systems Simulation
57	Doctoral Training Centre in Web Science
58	Doctoral Training Centre in Condensed Matter Physics
59	Doctoral Training Centre in Wind Energy Systems
60	Doctoral Training Centre in Medical Devices and Related Materials
61	Industrial Doctorate Centre in Advanced Forming and Manufacture
62	Doctoral Training Centre in Next-Generation Accelerators
63	Industrial Doctorate Centre in Micro and Nano Materials and Technologies
64	Industrial Doctorate Centre in Sustainability for Engineering and Energy Systems
65	Industrial Doctorate Centre in Manufacturing Advances Through Training Engineering Researchers
66	Doctoral Training Centre in Security Science
67	Industrial Doctorate Centre in Urban Sustainability and Resilience
68	Industrial Doctorate Centre in Molecular Modeling & Materials Science
69	Doctoral Training Centre in Financial Computing
70	Industrial Doctorate Centre in Bioprocessing Engineering Leadership
71	Doctoral Training Centre in Photonic Systems Development

72	Doctoral Training Centre in Energy Demand Reduction and the Built Environment
73	Industrial Doctorate Centre in Virtual Environments, Imaging and Visualization
74	Doctoral Training Centre for Mathematics and Physics in the Life Sciences and Experimental Biology
75	Doctoral Training Centre in Complexity Science
76	Doctoral Training Centre in Mathematics and Statistics
77	Doctoral Training Centre in Systems Biology
78	Doctoral Training Centre in Molecular Organization and Assembly in Cells
79	Industrial Doctorate Centre in High Value, Low Environmental Impact Manufacturing
80	Doctoral Training Centre in Magnetic Resonance Basic Technology
81	Fusion Doctoral Training Network
82	Industrial Doctorate Centre in Large-Scale Complex IT Systems
83	BGP2 Heritage Consortium
84	Centre for East European Language-Based Area Studies AHRC Consortium
85	London Doctoral Design Consortium
86	Northumbria-Sunderland Consortium
87	The 3D3 Consortium
88	The Design Star Consortium: “strength in diversity.”
89	London Arts & Humanities Partnership
90	The London and South-East Doctoral Research Consortium
91	University of Oxford AHRC
92	Cambridge AHRC Doctoral Training Partnership

93	Consortium for Humanities and the Arts South-East England
94	South, West and Wales Doctoral Training Partnership
95	The Midlands3 Cities Doctoral Training Partnership
96	The White Rose College of the Arts & Humanities
97	North West Consortium
98	Northern Bridge Doctoral Partnership
99	Scottish Graduate School for the Arts and Humanities
100	AHRC Doctoral Programme in Celtic Languages

Most of the DTP/Cs identified in Table 1 are mainly from the United Kingdom with funding support from the EPSRC, ESRC, and AHRC. With approximately 100 DTP/Cs in the United Kingdom alone (Table 1) through the combined effort of ESRC, AHRC and EPSRC indicates a hugely successful policy investment in the HEI.

Currently, in Africa, the World Bank-funded initiative of Africa Center of Excellence (ACE), supported by various African Governments, is dedicating effort toward doctoral and cutting-edge research in over 19 centers (Table 2) across the continent (The World Bank, 2014, 2019) with a focus on Science, Technology, Engineering and Mathematics (STEM). Mweetwa et al. (2021) revealed that, through RUFORUM and ACE doctoral training programs, approximately 420 doctoral students had been trained to support research, industry, and teaching. The American system essentially pushes toward graduate schools traditionally rather than toward this new dedicated doctoral training approach. For example, the focus of ACE, AHRC, EPSRC, and ESRC in research and general scholarship in specific disciplinary areas indicates that various forms and categories of knowledge are produced as outputs.

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DTP/C Strategies, Prospects and Challenges

DTP/Cs are here to stay. Some centers have collapsed because of funding cut challenges (Michael, 2019), nonrenewal of grant projects, interdisciplinary issues on collaboration, and leadership sustainability challenges. However, most of these centers remain sustainable (Bolger, 2021). Most DTP/Cs, therefore, adopted several sustainable strategies, networking and research approaches for long-term doctoral training and advanced research. Some of these approaches and strategies are examined below.

Table 2

Africa Centers of Excellence (ACE) for Research and Postgraduate Studies

No.	**Name**	**Institution/University**	**Country**	**Focus Area**	**Classification**
1	Training and Research in Water Science and Technology, Energy and the Environment in West and Central Africa	*Institut International d'Ingénierie de l'Eau et de l'Environnement* (2iE)	Burkina Faso	Water, Energy, and Environment	*STEM
2.	Regional Water and Environmental Sanitation Center, Kumasi	KNUST	Ghana	Water & Environmental Sanitation	STEM
3.	West African Center for Cell Biology of Infectious Pathogens and Non-Communicable Diseases	UG	Ghana	Cell Biology of Infectious & Non-Communicable Diseases	Health
4.	West African Center for Crop Improvement	UG	Ghana	Crop Improvement	Agriculture
5	The African Center of Excellence in Mathematics, Computers	UGB	Senegal	Digital Development	STEM
6	Maternal and Infant Health	UCAD	Senegal	Maternal & Infant Health	Health
7	Training, Research and Expertise in Drug Sciences	Ouaga I	Burkina Faso	Pharmaceutical Science	Health
8	Biotechnological Innovation for the Elimination of Vector-Borne Diseases	UNB	Burkina Faso	Biotech and Vector Transmitted Diseases	Health
9	Regional Transport Research and Education Center, Kumasi	KNUST	Ghana	Transport	STEM
10	Regional Center for Energy and Environmental Sustainability	The University of Energy and Natural Resources (UENR)	Ghana	Power	STEM
11	West African Center for Water, Irrigation and Sustainable Agriculture	University of Development Studies (UDS)	Ghana	Water & Irrigation	STEM
12	Coastal Resilience	University of Cape Coast (UCC)	Ghana	Coastal Resilience	STEM
13	West African Genetic Medicine Centre	UG	Ghana	Genetic Medicine	Health
14	Prevention and Control of Communicable Diseases (	Université Gamal Abdel Nasser de Conakry (UGANC)	Guinea	Communicable Diseases	Health
15	Environment and Health	UCAD	Senegal	Environment & Health	STEM
16	Agriculture for Food and Nutrition Security	UCAD	Senegal	Food Security & Nutrition	Agric
17	Emerging Center: Logistics and Transport	*Université de Djibouti* (UD)	Djibouti	Transport—Logistics	STEM
18	Emerging Center: Mines and Societies	ISMGB	Guinea	Mining	STEM
	Add-on Support to Colleges of Engineering				
1	College of Engineering	KNUST	Ghana		STEM
2	College of Engineering	Université de Djibouti	Djibouti		STEM

DTP/C Strategies

As centers dedicated to research that seeks to bridge the gaps between real-life problems and scientific knowledge, coherent methodological frameworks have been developed to advance their goals. These strategies

cover the interest of the funding bodies, the private sector, societal challenges, early career researchers, and admitted PhD students.

- Research
- Networking
- Cross-disciplinary
- Experiences and a team of doctoral researchers
- Training
- Business and industry engagement

To address the significant gap between market needs and available skills and labor, the European Union has proposed a strategy for matching new skills for new jobs (European Union, 2010). The key messages that were proposed in the strategy highlighted the following needs:

- offer appropriate incentives for enhancing skills
- merge education, training, and work and enhance the relationship between these different sectors
- identify the right mix of skills needed
- identify the trends and changes in skill needs for the future as well

DTP/Cs, a critical number of those within Europe, have taken on this challenge to anticipate the current and future skill needs of work within academia, the private sector, and governmental institutes. They redefine doctoral programs from preparing successors for academicians to training for high-level positions in careers within and outside academia. Expanding the PhD experience to prepare doctoral graduates to succeed in a career range does not require a significant overhaul of graduate programs. This has been recognized by DTP/Cs, which principally follow the basic graduate school program and include focused seminars in areas such as communication and networking, management skills, and public policy. These areas are chattels that would significantly enhance and strengthen the

capabilities of PhD students as well as improve their career prospects (Fiske, 2011).

Through DTP/Cs, doctoral students are funded for an agreed length of research and training (three to four years on average). This duration focuses on research and professional development and enhances the students' transferrable skills (EPSRC, 2019). Funding for these programs is usually sourced from a partnership with a specific body, e.g., industrial institutes, foundations, governmental bodies, specialized research centers, and universities. This fosters links with nonacademic institutes, which allows PhD holders to explore careers beyond academia and provides industry and other sectors to harness the potential of PhD training.

Research

One of the critical reasons for establishing DTPCs is to support crosscutting and focused research that empirically contributes to knowledge. These bodies thus try to tackle real-life problems by creating research projects for students. Students and researchers generally rely on their set of networks and the existing structural networks their institutions and projects provide. To execute the research responsibility, it will typically take two to three and a half years to complete their doctoral research under an academic supervisor or small supervisory team's guidance. Additionally, the researcher would tend to be located within an existing research group of the university, the research institution, and very rarely the funding body. Overall, these centers enhance quicker ways of turning vast research output volumes with some 100, 200, or 300 years of postgraduate research. This process is argued to have a cumulative effect on the researched projects and issues.

Networks

Bardach (1994) examined networks to be sets of self-organizing working relationships among actors such that any relationship has the potential to elicit action and communicate information efficiently. O'Daniel and Rosenstein (2008) add that creating applicable linkages within and among communities, organizations, and societies is essential to achieving various goals. Both Bardach (1994) and O'Daniel and Rosenstein (2008) argued that researchers and actors within agencies need to work together for efficient and effective knowledge production and better outcomes. Working together is either facilitated by the agency or through institutional networks and researchers' informal level.

Conferences, seminars, symposiums, and colloquia are also critical sources that the scientific and academic communities use to enhance their disciplinary networks and lobby for support and favors. Joint and interdisciplinary projects and funding often become the outputs of such events (Bridle et al., 2013). As the world becomes complex, networking and building relationships with these knowledge communities and other actors serve as a step for better collaboration among the research community (Harris & Lyon, 2014; Stirling, 2015). The DTP/Cs believe that doctoral training programs serve as the platform for students to uniquely set themselves apart while working at the cutting edge of research and networking with other specialists in different fields related to the center. DTP/Cs are considered successful if there exist knowledge-sharing processes, collaborative research initiatives, sustainable co-funding, and research planning priorities (QAA, 2013).

Experiences and Team of Doctoral Researchers

The generational gap always exists in all spheres of life (Ninan, 2013). HEIs and the DTP/Cs are mentoring platforms for young researchers and doctoral students. Postdoctorate researchers and other early career

researchers are normally tasked in these centers to guide and mentor students with support from students' main supervisors (Afonja et al., 2021) to enhance knowledge transfer between research, funding processes, business community linkages (Deloitte, 2012) and partnerships (Amrita et al., 2021).

For example, in South Africa, the South African Young Academy of Science (SAYAS) serves as a mouthpiece to groom young researchers and scientists to contribute to national and global challenges. The experience learnt also helps shape and influence local-level policy decisions and contribute to developing the scientific capacity of the youth through mentoring and rolemodeling and fostering opportunities for the students' interdisciplinary collaborations (SAYAS, 2013).

Again, considerable experience is learned in teams and interdisciplinary projects led by experienced senior researchers to guide and impact transferrable knowledge and research skills to doctoral students (Schneijderberg, 2021). All the various DTP/Cs in the United Kingdom have teams of doctoral researchers in cluster or theme forms who collectively work toward the primary goal of each DTP/C or the funding body.

The DTP/Cs Elements of Training of Doctoral Students

Morales (2017) explains that universities and other higher educational institutions are now shifting toward intertransdisciplinarity in pursuit of creative and innovative ways to solve the world's complex problems, focusing on collaborations in research projects and curricula. The norms followed by DTP/Cs are to offer training programs grouped by skill sets (professional, personal, etc.) or level of progression (early career, mid, late). Flexibility in delivering these training sessions is imperative in the DTP/Cs since doctoral students are expected to be occupied with their research, writing, meetings, and other engagements.

Interdisciplinary graduate schools and DTP/Cs are considered ideal for advancing an effective knowledge coproduction process. However, Kiley (2010) argues that tendencies for a frosty and complicated student-supervisor relationship are high, considering the cross-disciplinary and cosupervising arrangements that often come with the programmes. What often undermines the collaborative process and knowledge transfer are methodological and multiple theoretical considerations by assigned supervisors under such programs (Nisselle & Duncan, 2008; Taylor & Beasley, 2005), thus causing many graduation delays if not an abrogation of the PhD programs. This remains a critical area for discussion in HEIs.

As important as training is for DTP/Cs, its core program is researchbased training. DTP/Cs aim to develop scientifically trained professionals who are competent in a wide area of skills yet specialize in a specific area. Thus, a larger emphasis is placed on research and research-related skills. It is rarely easy to balance the depth of science and professional development's core principles, a challenge that DTP/Cs attempt to tackle. DTP/Cs' approach to tackling this challenge is by including the following elements in their programs:

- multiple supervisors
- multiple research sites or locations
- training beyond specific research skills, e.g., patents, proposal writing, community engagements, corporate social responsibilities, etc.
- encouraging independent research and authoring papers
- work in multidisciplinary teams and communicate with nonexperts
- crossing the interdisciplinary approach into transdisciplinary approaches with nontechnical groups
- use of online modules
- focus on specific fields—specialization remains important
- equality, diversity, and inclusion

The DTP/Cs aim to develop scientifically grounded professionals adapted to work within and outside academia. This dual objective requires a versatile training program that addresses academic expertise and personal skills, balances critical thinking skills/research, and administers skill development. In addition to the research-based training, PhD researchers follow more formal training via seminars, workshops, summer schools, and other course components. The doctoral researcher must develop transferable and generic skills and competencies in the doctoral training program process. Many students follow structured courses outside the lab, including classes in report writing and other transferable skills. These skills exceed the specific PhD topics applicable in a broader context, e.g., a professional career outside the university. Such skills are interdisciplinary thinking, networking, goaldirectedness, prioritizing, creativity, and innovation (KU Leuven Arenberg Doctoral School, 2021).

Business and Industry Engagement Model of DTP/Cs

Knowledge, skills, and innovation constantly overlap, with each sector offering support to one another. Today's economy is driven by knowledge and skills, cumulatively leading to improved technologies and productivity and accelerating economic growth. Doctoral degree holders play a key role in transferring scientific advancements and technical improvements into their strategies and forming a robust, innovative force (Edmondson et al., 2012). Students obtain a good amount of money working with private, public and third/voluntary sector organizations during their doctorate studies and are encouraged to take such opportunities of 1800 hours yearly (ESRC, 2015). This often serves and remains the starting point in their career development postPhDs, especially if graduates are not interested in joining academia.

Thus, ensuring constant updates of helpful knowledge and data within the corporate sphere enhances students' capacities to absorb new

technology. There is no denying that the PhD supply market is saturated at this point, outnumbering the demand for PhDs by universities (Pinto, 2021; Reis, 1997). Universities traditionally were the largest consumers of PhD holders.

However, the Royal Society United Kingdom commissioned study (CRAC, 2018) highlighted that 3.5% of PhD degree holders in science became tenured staff, while a staggering 80% pursued careers outside nonrelated to scientific research. Meanwhile, the industrial sector, which could benefit from this highly skilled labor supply, often struggles to incorporate them as doctoral degree holders claiming they lack the necessary skills for their industry.

Restructuring doctoral courses to offer appropriate training for their students while addressing societal problems is the current focus of DTP/Cs. The focus is on rebranding doctoral degree holders as creative problem solvers and critical thinkers, managers and team players, strong communicators, etc., capturing all the skills they develop as influential researchers. The development of transferrable skills such as teaching and mentoring (Schneijderberg, 2021), project management, and written and oral communication needs to be intrinsic content of the doctoral curriculum.

The Funding and Communication Challenges of DTP/Cs

The DTP/Cs model ambitiously addresses the challenges of the old and conventional doctoral models. The centers and programs have significantly contributed to advancing science, research, and innovation. A review of the over 50 DTP/Cs, especially in the United Kingdom and Europe, reveals that scientists in these establishments have received considerable funding, contributed to knowledge and discoveries, and trained many doctoral and postdoctoral scholars for tomorrow's world (Afonja et al., 2021). Nonetheless, they still face significant challenges, some including the following.

Funding

Funding for DTP/Cs is usually sourced from partnerships, including national governments, international development organizations and the private sector/industry. Based on how the funding processes are packaged, stringent conditions governing the research interests and direction of student development are added. Additionally, it tends to introduce capitalistic elements in the research process, as some funders and partners expect a return on investments for their financial contribution. In short, the research outputs must serve their interests and not solve real-life and societal challenges.

In addition, most DTP/Cs cannot provide a holistic funding scheme covering stipends, tuition, logistics and consumables, travel costs, scientific conferences, etc. Student mobility systems under the DTP/Cs appeared not to be very effective due to funding gaps. However, such an approach aims to foster exchange and collaboration among partners during the research cycle. In the United States, postgraduate students will have to spend much time scouting for funding if they do not want student loans, which is a considerable burden and takes several years to pay postgraduation (Michael, 2019). This funding challenge often reduces the efforts and passion for pursuing doctoral studies limits deeper insights and focuses on unearthing scientific novelties. In particular, the European Union suggested that public institutions responsible for higher education sustain a well-funded higher educational system for effective teaching and learning (McAleese et al., 2013). Financial sustainability appeared to be the solution the DTP/Cs offer to students compared to traditional PhD programs. DTP/Cs encourage industrial investment involvement in the academic and research field, where most of the funding comes from governments, foundations, and research trust funds.

Communication

Communication remains critical in creating better relationships and interactions between doctoral students and their supervisors (Sonia et al., 2019). It enhances the positive bond with advisors (Mazerolle et al., 2015) when anchored on clear-cut communication processes outlined when it is open with some level of trust among supervisors and students (HardingDeKam et al., 2012).

When different technical disciplines engage, a language may be misinterpreted, leading to troubled communication. Moreover, communication between industry and academia will offer another added challenge. Disciplinary language and cultural differences are often considered barriers to communication, collaboration, and supervision (Schneijderberg, 2021). Intertransdisciplinary approaches often facilitate effective supervisors' and students' engagement to communicate and understand for a successful supervision cycle (Jill-Trewhella, 2009). Effective organizational and project communication strategies and critical intercultural communication skills with team members appear to address the barrier of "speaking one another's languages" in DTP/C teams.

Active participation during problem framing and concept development before starting research projects is essential to effective communication under partnerships. Therefore, academics and industry players are important actors in transdisciplinary team buildup (Mumuni, 2018). The knowledge generated will represent all actors' views, including academic and nonacademic researchers working together to solve a problem (Cronin, 2008). In solving the problem, the decision-making process of projects and institutional leaders depends primarily on them and not all members. Effective and clear communication in supervision teams, the DTP/Cs and the industry are likely to enhance better-coproduced knowledge that serves the interest of all the stakeholders involved (Aenis,

2010; K. L. Hall et al., 2012; T. E. Hall & Rourke, 2014; Mumuni, 2018; Siew et al., 2016).

DTP/CS and the Transdisciplinarity Nexus

The university and higher education environment have adopted the interdisciplinary concept and approach for a long time now, especially in program development and research scopes and projects (Staniskis & Stasiskiene, 2006). The effort aims to broadly develop holistic research outputs and approaches to addressing 21st-century challenges and complexity. The DTP/Cs, as espoused in this paper, reveal the involvement of academia, the business community, and the industry in developing research projects at the doctoral centers' levels and universities. Set that way as a strategy, each of these groups is expected to play significant roles, including research in the academic environment, sourcing funding from the business community, and facilitating industrial experiences and exchange for students (Edmondson et al., 2012). The significance of the DTP/Cs collaborative and integrative model involving all the relevant stakeholders means that strong innovative and critical knowledge is being coproduced using transdisciplinary approaches (Cundill et al., 2015). This involves the nontechnical actors or nonacademics, who help produce real reflective perspectives, solutions, and integrative knowledge to address complex issues, as argued by these scholars (Klein, 2010; Leeuwis, 2000; Nicolescu, 2010; Noe & Langvad, 2008; Pohl, 2005; Recha et al., 2014). Hence, the nexus of the DTPs and the strategy of collaboration and working together with the business environment and industry further entrench the critical need for such scholarly centers in higher learning institutions (Edmondson et al., 2012).

A transdisciplinary approach is often argued to focus on every stakeholder in a team and is only adopted when the problems at stake are

complex and cannot be addressed by existing single disciplines or at the interdisciplinary level (Klein, 2010; Mumuni, 2018; Nicolescu, 2010; Norström et al., 2020). Hence, in the view of this paper, the involvement of nonacademics such as the industries in the formulation of the doctoral project process means that actors in such teams vary in terms of knowledge, academic training, and interest. The principle and the elements of transdisciplinarity can address these nuances for practical enhanced knowledge coproduction.

CONCLUSIONS

As examined, much progress has been made since the doctoral training centers and partnerships in the scientific knowledge contribution process, development of human resources (doctoral scholars), and the innovative solutions adopted to address our collective needs today. Nonetheless, critical issues and other institutional leadership and formalities appeared to be challenges facing the DTP/Cs model. In addition to developing and sustaining industry interest in postgraduate studies, funding and critical knowledge inquiry are nuanced issues that need to be addressed. The use of a transparent communication process, setting up clear goals and targets with students with noncoercive consent and strengthening the formal institutional structures that take care of and address every actor's need and requirement remain critical to addressing these dystopian issues of doctoral studies.

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